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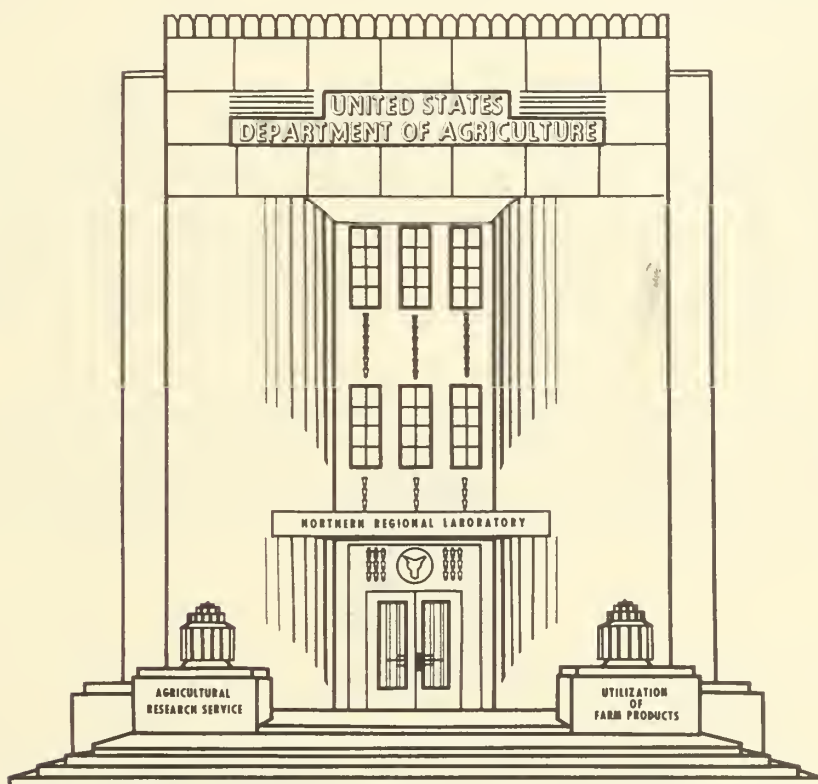
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CHEMICAL ENGINEERING IN FERMENTATIVE PROCESSING



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Growth Through Agricultural Progress

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CHEMICAL ENGINEERING IN FERMENTATIVE PROCESSING¹

By

Virgil E. Sohns²

The fermentation industry in its various processes affords an opportunity to use most of the unit operations generally associated with chemical engineering. In fact, few of the typical chemical processes utilize the variety of unit operations as do certain individual fermentation processes. A classic example is the fermentation of grain to produce ethanol.

A commercial ethanol process ordinarily includes grinding, mixing, heat transfer, flow of fluids, mashing and fermentation, distillation, filtration, and evaporation. These operations are a combination of chemical engineering and biological techniques. Similarly, fermentation processes that have been developed or are now being developed as a part of the U.S. Department of Agriculture's program to broaden the use of agricultural crops include these techniques.

Microorganisms are used extensively to convert grain constituents into new and diverse compounds, thereby providing a promising route for increased utilization of grain. The Northern Regional Research Laboratory³ through its ARS Culture Collection and staff of fermentologists has assumed a prominent role in the development of new fermentation

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³ The Northern Regional Research Laboratory is headquarters for the Northern Utilization Research and Development Division.

processes. It maintains a permanent collection of about 8,500 species and strains of industrially and agriculturally important bacteria, molds, and yeasts. This collection is used by microbiologists in their search to find organisms that will synthesize a wide variety of industrial chemicals. Once laboratory studies confirm that a product of industrial interest can be produced by an organism, process engineering studies follow. This paper describes the application of chemical engineering principles to selected fermentative processes that have been conducted at the Northern Laboratory.

FERMENTATION STAGE

Investigations on fermentations have included processes for the production of vitamins and feed supplements, organic acids and salts, microbial polymers, and fungal enzymes. The fermentation stage of these processes or similar ones requires that the chemical engineer have some knowledge of the problems associated with the handling of microorganisms. Conditions for conducting the fermentation must be such that the micro-organism will follow its natural cycle and will produce the compound desired in acceptable yield.

All the processes mentioned require pure culture conditions and must be operated aerobically. Engineering studies associated with these two conditions will be emphasized primarily, although other factors such as nutrients for medium, pH of medium, and incubation temperature are investigated in each process. For all submerged pure-culture fermentations, the following major requirements must be fulfilled to maintain aseptic conditions: Equipment such as fermentors and allied units that come in contact with the medium must be sterilized, sterile air must be provided, and the medium to be fermented must be sterilized.

The equipment to be sterilized is usually steamed at 15 lb./sq. in. gauge for several hours, with the necessary precautions being taken to eliminate "pockets" or "dead ends" that might be a source of contamination in the system. Air for the fermentation may be sterilized by chemical means or by heat of compression (10),⁴ but in ordinary plant practice

⁴ Italic numbers in parentheses refer to Literature Cited, p. 20.

filtration through a medium such as cotton, fiberglass, or activated carbon is preferred. This method is sure and simple, and maintenance at least for activated carbon filters is low. If an activated carbon column is steamed at 15 lb./sq. in. gauge for a few hours at regular intervals, the filter can be used repeatedly for almost an indefinite period. An air filter must have a minimum capacity sufficient to satisfy the requirements of a particular operation, but the methods used to determine the capacity of a unit generally are based on empirical data since only meager data are available on the theoretical aspects of this problem.

A system for continuously sterilizing the fermentation medium with steam has become accepted in pilot-plant or commercial installations (4). This method has definite advantages over batch sterilization, in that the nutritive value of the medium is not affected, labor and material costs are reduced considerably, the process can be adapted to automatic control, space requirements for equipment are less, and there is a savings in steam costs since the steam load is constant.

The basic elements of a continuous sterilizing system include: Tanks for mixing ingredients prior to sterilization; a pump for transferring the medium to a jet heater and through the holding section; a jet heater or similar device for instantaneously heating the slurry to sterilization temperature; a holding section which usually consists of a series of interconnected pipes in which the medium is retained at sterilization temperature until it is sterile; and a heat exchanger to cool the sterile medium to incubation temperature as it flows to the fermentor. A continuous sterilizer for pilot-plant use is shown in figure 1.

In the operation of a continuous sterilizer, the pumping rate is adjusted to give the proper retention time within the holding section, the capacity of which has been determined. It is essential in obtaining a sterile medium that all of it be held at sterilization temperature for the same or nearly the same period of time. The fluid therefore must be in a condition of turbulent flow while in the holding section of the sterilizer. Fluid flow in this section must be such that a Reynolds number above 3,000 is attained; in most continuous sterilizers, the Reynolds number is in excess of 20,000 or well above the minimum required to give turbulent flow.

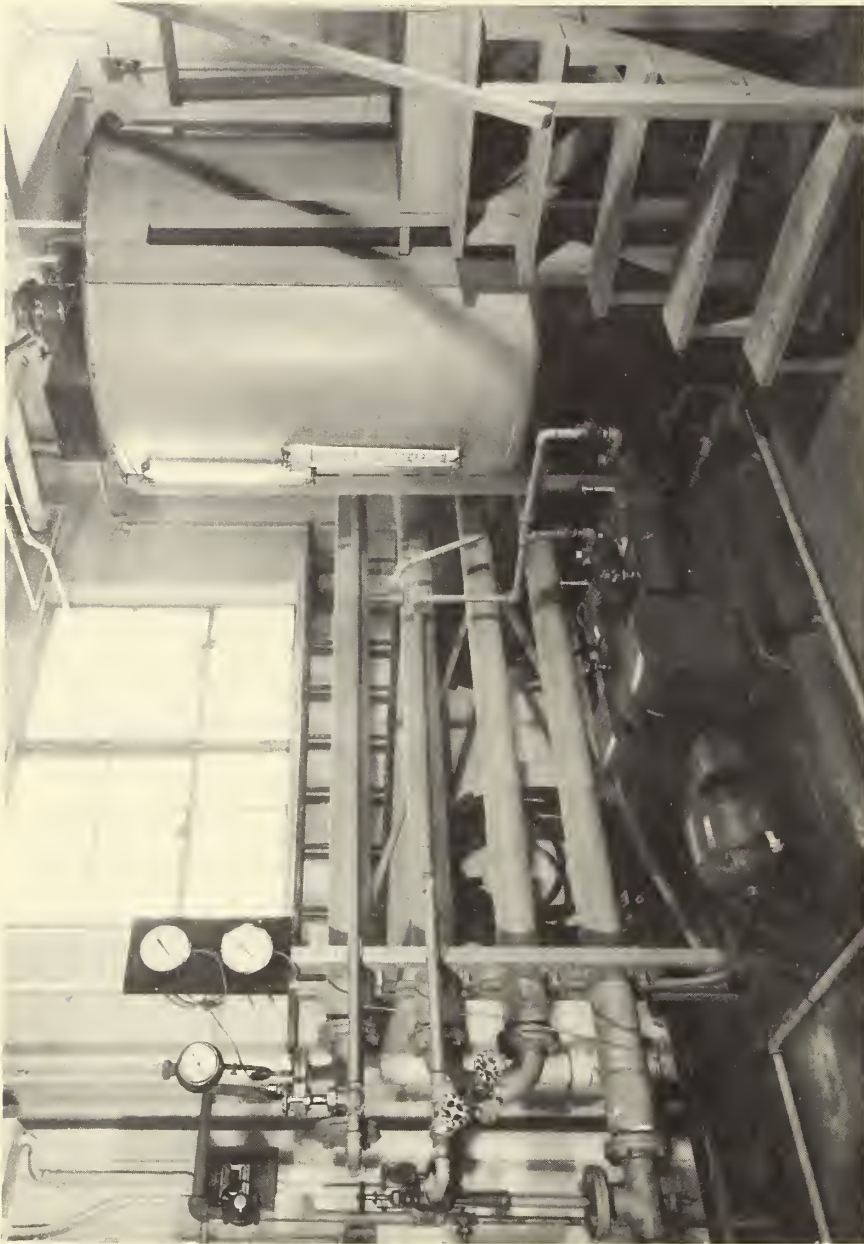


Figure 1.--The continuous sterilizer used in the pilot plant of the
Northern Laboratory

Conditions for continuous sterilization may vary widely and will depend upon the nature of the slurry to be sterilized. A medium consisting of dextrose, corn steep liquor, and soluble salts, which has a low suspended solids content, is relatively simple to sterilize and a retention time of 3 minutes at a temperature of 275° F. (30 lb./sq. in. gauge) frequently suffices. If coarse suspended solids like ground corn or soybean meal are present in the slurry, a more vigorous treatment such as 12 to 15 minutes at 325° (approximately 80 lb./sq. in. gauge) may be required. The pH of a medium exerts an influence on the ease with which the medium may be sterilized. Ordinarily, sterilization at pH 4.0 should be easier than if the liquor has a pH approaching neutrality.

Foaming characteristics of a medium may also be affected by sterilization conditions. In studies conducted on the production of sodium gluconate when the medium was batch sterilized, it exhibited no foaming tendencies, but when it was sterilized continuously at 275° for 5 minutes, foaming became evident during fermentation. Because each type of medium has its own peculiar characteristics and because a variety of factors must be considered, optimum conditions for sterilization are best determined by experiment in every case. The effect of conditions for sterilization on the yield in a fermentation is shown in table 1.

TABLE 1.--Effect of method of sterilization on the yield of riboflavin produced with the organism *Ashbya gossypii* NRRL Y-1056¹

Method	Sterilization			pH	Maximum riboflavin yield
	Temperature	Time			
	°F.	Min.			Y/ml.
Batch-----	250	45	:	6.5	5
Continuous-----	275	5	:2	6.5	360
Batch-----	250	25	:2	4.4	88
Continuous-----	275	5	:	4.5	656
Do-----	275	5	:	4.5	608

¹ Medium contained 2.0 percent glucose, 1.9 percent corn steep liquor, 1.0 percent animal stick liquor.

² Stick liquor sterilized separately.

Aeration conditions for each fermentative process also are determined experimentally and depend upon the requirements for the fermenting organism. The quantity of air and speed of agitation needed to meet these requirements depend upon the dimensions of the fermentor and the type of the aerating system used.

Fermentors used in the various fermentative processes developed as part of our utilization research program have included units with a variety of shapes, capacities, and accessories. Baffled tanks are preferred over unbaffled tanks, because baffled units eliminate the formation of a vortex when the medium is being agitated and thus provide a more efficient aeration system.

Top-entering variable-speed agitators are standard equipment in most fermentors, although side-entering agitators have been used with limited success. Contamination from the packing glands in side-entering mixers can constitute a serious problem. Agitator impellers most generally are flat-bladed turbines, although satisfactory results have been obtained with other types. Air is introduced under the agitator blade through an ordinary perforated ring or cross-type pipe sparger or merely through an open-end pipe. The ratio of depth of liquid to diameter of vessel may vary from 3:1 to less than 1:1, depending upon the particular fermentor and volume of liquid used. In general practice, a ratio in the range of 1.5 or 2 to 1 is considered optimum.

Rate of oxygen absorption as determined by the sulfite oxidation method (2) is known for each of the aerating systems at various rates of agitation and superficial air velocities. Having determined the oxygen absorption characteristics for each aeration system, satisfactory results can be obtained in any vessel for all fermentative processes by carefully selecting the agitator speed and air velocity.

In some instances optimum conditions for aeration, insofar as rate of fermentation and yield of product are concerned, may cause serious foaming problems. If foaming is so severe that controlling it is impossible without the addition of excessive quantities of antifoam agents, some adjustment must be made to the aerating system that will reduce the foaming tendencies of the liquid without unduly affecting the fermentation in other respects. The oxygen absorption rate, as determined by sulfite oxidation for most

fermentations that have been conducted, is in the range of 0.2 to 1.0 millimole of oxygen absorbed per liter per minute. Such oxygen absorption rates require that a net power of 0.5 to 1.5 hp. per 1,000 gal. be dissipated by the agitators in the fermenting medium. Fermentations in which the medium becomes very viscous may require as much as 10 hp. per 1,000 gal.

Control of foaming during fermentation is usually accomplished by the addition of some suitable antifoam agent. Silicone, soybean oil, or octadecanol dissolved in ethanol are frequently used for foam control. The choice of agent will depend upon the kind of fermentation that is being conducted, because some antifoam materials may have an inhibitory effect on the fermenting organism. Since the addition of antifoam agents to a medium adversely affects the oxygen absorption characteristics of the system, excessive addition of any agent should be avoided. If foaming is a problem, the fermentation equipment should include a system that adds the antifoam agent automatically. An electronic foam controller has operated successfully for this purpose (3). Such a controller is actuated when foam in the fermentor touches an insulated electrode and small amounts of antifoam agents are added through a solenoid valve as permitted by a timer.

Automatic pH control instrumentation can be extremely useful in certain fermentation processes. The production of sodium gluconate (1) and of dextransucrase (2), an enzyme that converts sucrose into dextran, are processes in which automatic pH control has been used with considerable success. Such equipment permits control of pH within close limits; in the dextransucrase fermentation, particularly, close control is essential, since production of the enzyme is sensitive to small variations from the optimum pH level.

Instruments for automatic control of temperature and air flow in the medium are additional accessories which are provided for many fermentor installations.

RECOVERY STAGE

Although recovery of industrial fermentation products may involve operations that are common to the chemical industry,

frequently problems are encountered that are peculiar to the fermentation industry alone. In many fermentation processes, the first step in recovery entails removal of microorganisms or mycelia from the fermented liquor or so-called beer. Usually, this step is accomplished by filtration or centrifugation. If a feed supplement or crude product is recovered, removal of the organisms is usually not necessary; merely concentrating and drying the whole beer may be sufficient to get a product of acceptable quality.

The filtration characteristics of fermented beer may differ considerably, not only between types of processes, but also between different runs in the same process. Filtration qualities of some beers will be determined by their natural characteristics, but operating conditions during fermentation may also have an influence on filtration of the beer.

In some fermentations autolysis of the organism may occur if a batch is permitted to continue for an appreciable time after fermentation is substantially complete and when this occurs, filtration becomes more difficult. Another factor that may influence filtration is the pH of the finished beer when it is processed. Slurries that are difficult to filter are encountered in fermentation processes as they are in many other processes, and adding filter aid usually has a profound influence on the rate of filtration. Experiences encountered in the filtration of fermented liquor from the calcium 2-ketogluconate process (7) are typical of this problem. Filtration was much faster in batches where the pH of the finished liquor was below 6.0 and when filtering was done immediately upon completion of the fermentation. The addition of 2.0 percent filter aid to the fermented liquor further facilitated filtration. Plate and frame filter presses, horizontal plate filters, and continuous vacuum filters have been used in various fermentative processes for filtering the fermented liquor.

In some processes, either centrifugation or filtration can be used satisfactorily to remove the fermenting organisms, but when filtration rates are so low as to be impractical, centrifugation may be an almost absolute requirement. For example, when yeast hydrolyzate was one of the ingredients used in the medium to produce dextransucrase, the fermented beer could not be filtered, but centrifugation through a supercentrifuge was effective in producing a liquor of suitable quality at an acceptable rate.

Concentration of the fermented liquor usually is required in processes that include crystallization and/or drying to recover the final product. Concentration of the liquor is accomplished by evaporation before clarification of the beer like the production of feed supplements or after clarification like the production of sodium gluconate. For heat-sensitive materials, evaporation is conducted at reduced temperatures and may demand the use of a film-type evaporator or similar unit. Protective agents such as antioxidants sometimes can be added to the liquor before concentration to prevent loss of vitamins or other vital ingredients. If a relatively heat-stable material is processed, multiple effect evaporation may be advantageous because of steam economy.

The procedures for recovering the desired material from the concentrate will depend upon the particular product involved, the quality specified for it, and the form in which it is to be recovered. Ordinary crystallization techniques with standard equipment are used for the recovery of certain organic acids and salts. Crystallization may be preceded by a treatment of the beer or the concentrate with decolorizing carbon if a material substantially free of color is needed. Separation of the crystals can be accomplished in a perforated basket centrifuge. This system of operation can be conveniently used in recovery of itaconic acid and calcium 2-ketogluconate.

Generally, recovery of fermentative products will include drying. This operation may involve any one of several types of driers, with either spray or drum driers most frequently being used. To avoid overheating a material, spray drying may be suitable since residence time in the drier is only a few seconds. For example, spray drying is preferred in the production of clinical dextran. Operating with an inlet air temperature to the drier of approximately 450° F. and an outlet air temperature of 190° produces a dried dextran which is a white, powdery product with properties unchanged from the wet material. For materials that are fairly heat resistant, drum drying is suitable. In the fermentation processes investigated, atmospheric drum drying on double drum driers is used exclusively rather than vacuum drum drying. Vacuum drum drying may have its application in other processes but the cost of vacuum drum drying often limits its use. Tray driers and rotary vacuum driers comprise other units in which drying is conducted.

Some fermentative processes may require procedures distinctly different from those that are applied to most other fermentations. Polysaccharides produced by fermentation are precipitated by the addition of methanol to the filtered beers, after which the polymers are dried to yield the final product. In the production of clinical-sized dextran, the molecular weight of the precipitated material can be controlled by the addition of alcohol, within established limits, to a hydrolyzed beer. A peculiar condition occurs in the recovery of certain polysaccharides, in that the extremely high viscosity of the final beer complicates recovery operations. This difficulty can be overcome by adding an electrolyte to the beer, such as potassium chloride, which reduces the viscosity of the liquor and also causes the material to precipitate more readily (8).

Resin columns have found considerable application in the purification of fermentation products. Anion and cation exchangers were used effectively to reduce the ash content of clinical-size dextran sufficiently that it met military specifications. Resin columns are also used by the antibiotic industry to remove the active ingredients from a slurry, but this operation and such others as freeze drying and dialysis were not utilized in the processes included within the scope of this paper.

TYPICAL PROCESSES

Developmental studies on the fermentation and recovery of vitamin B₁₂ and of itaconic acid illustrate the use of various chemical engineering techniques and their effect in the production of these materials.

Vitamin B₁₂

The Northern Laboratory process to produce vitamin B₁₂ by fermentation of Streptomyces olivaceous (6) has been adapted commercially, and the dried product from this process is employed in the manufacture of animal feed supplements. A satisfactory medium for this process contains 4 percent of a mixture of distillers solubles and extracted, unheated soybean meal, 1 percent dextrose, 0.5 percent calcium carbonate, a source of cobalt at a concentration of 2 to 10 p.p.m., and a suitable antifoam agent. Both batch and continuous sterilizing

methods were employed in our investigations. The effect of the method of sterilization on the yield of vitamin is shown in table 2. Because metal contamination can be a vital factor in this fermentation, the operating conditions will depend somewhat upon the material of construction for the fermentors. Successful batches were run in stainless steel and in steel fermentors when either batch or continuous sterilization methods were used. In copper fermentors batch sterilization was satisfactory only if the pH of the medium was raised to 7.0 prior to sterilization. At low pH, copper is dissolved in the medium during sterilization and has a deleterious effect on the organism.

TABLE 2.--Effect of method of sterilization on yield of vitamin B₁₂ produced with organism Streptomyces olivaceous NRRL B-1125¹

Sterilization				Tank	Yield of B ₁₂
Method	Time	°F.	pH		
					Mg./liter
Batch	2 hr.	250:	4.8	Copper	0.2
			7.2	do.	.9
			4.5	Stainless steel	1.0
Continuous	13 min.	330:	4.8	Copper	1.2
			6.5	do.	1.3
			4.5	Stainless steel	1.3
			4.5	Steel	1.2

¹ Medium contained 4 percent distillers solubles plus unheated extracted soybean meal, 1 percent glucose, 0.5 percent CaCO₃, 0.1 percent soybean oil, 10 p.p.m. CoCl₂·6H₂O.

The rate of oxygen absorption also has a definite effect on the rate of production of vitamin B₁₂. Figure 2 indicates that an oxygen absorption rate of not less than 0.4 liter of oxygen absorbed per liter per minute is needed to obtain acceptable yields of 1.2 to 1.3 mg./liter in 72 hours. The correlation of rate of vitamin production to oxygen absorption rate was similar for the various fermentors used in this work, even though these units differed in power input, aeration efficiency, and design.

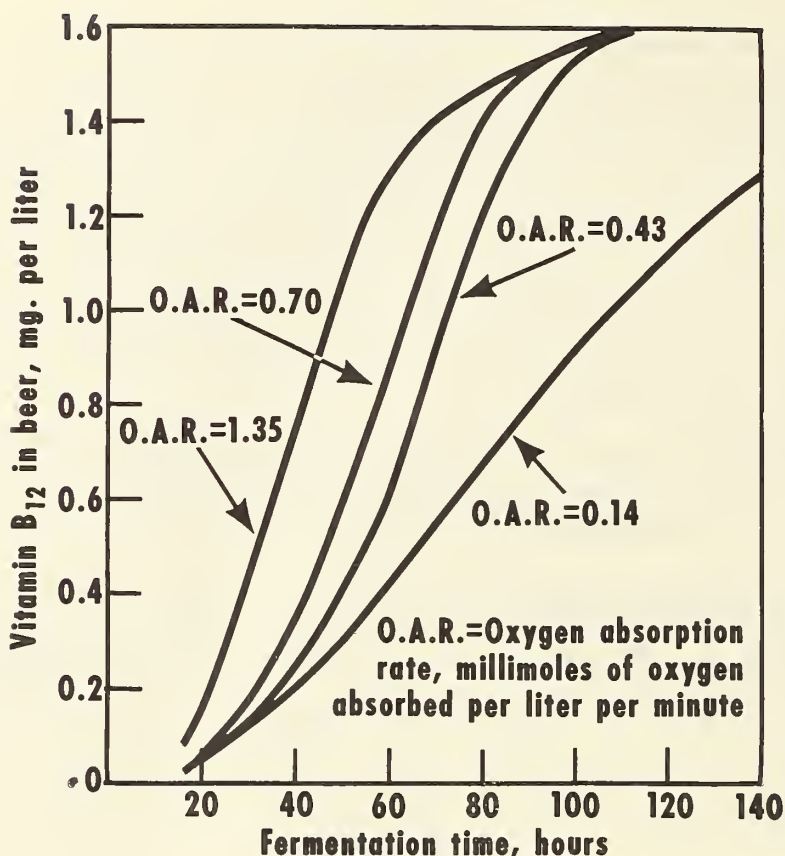


Figure 2.--Effect of rate of oxygen absorption on the production of vitamin B₁₂ by the process developed at the Northern Laboratory

Optimum temperature for this fermentation is from 78° to 82° F. and inoculum amounts to 5 percent of the volume fermented. The initial pH for fermentation is approximately 7.5; pH gradually decreases to 6.7 during the first 24 hours and then increases to near 9.0 at the end of the cycle. Before recovery operations are begun, the pH of the beer is adjusted to 5.0 with sulfuric acid.

To recover a concentrate from the whole beer, it is evaporated to produce a sirup of 20 to 25 percent solids.

Evaporations were conducted at temperatures ranging from 125° to 215° F., and dried concentrates prepared from the various sirups showed that about 80 percent of the vitamin present in the whole beer was recovered when evaporations were conducted below 180°. At temperatures above 180°, an additional loss of 10 percent was incurred.

Drum drying of sirups having a pH in the range of 4.1 to 7.5 showed that dried concentrates from such sirups did not vary significantly in their vitamin potencies. Steam pressure in the drums was 40 lb./sq. in. gauge.

To reduce losses of vitamin B₁₂ that occurred by the recovery methods described, the addition of protective agents to the whole beer was investigated. Adding such compounds as sodium thioglycollate, potassium cyanide, or sodium sulfite improves vitamin recovery significantly. When 100 p.p.m. of sulfite were added to the whole beer, average vitamin recovery in the dried product approached 90 percent as compared to slightly less than 80 percent when no agent was added. Dried concentrates produced in this manner contained from 15 to 17 mg. of vitamin per pound. Drum drying under vacuum even with low steam pressure in the drums offered no advantage. The potency of concentrates prepared by spray drying was about the same as that in drum-dried concentrates.

A concentrate of high vitamin potency may be prepared from the mycelium separated from whole, fresh, fermented beer. After the mycelium is suspended in water and the pH adjusted to 5.0, the slurry is heated to boiling and filtered or centrifuged. By drying the sirup that is produced through evaporation of the filtrate, a concentrate containing more than 100 mg. of vitamin B₁₂ per pound can be prepared.

Itaconic Acid

Another type of fermentation that has assumed increased importance in recent years is the production of organic acids. Itaconic acid is such a product (5) and it has potential uses in the manufacture of plastics, resins, elastomers, and surface coatings. A suitable substrate for producing itaconic acid consists of approximately 6 percent glucose, 0.27 percent ammonium sulfate, 0.08 percent magnesium sulfate, and 0.18 percent corn steep liquor.

Sterilization of the medium for this fermentation can be accomplished satisfactorily batchwise or continuously. Because iron exerts a toxic effect on this fermentation, precautions are necessary to avoid the introduction of iron into the medium from the steam that is used for sterilizing purposes. A well-trapped steam system is helpful in reducing the amount of iron from this source. Fermentors and other equipment coming in contact with the fermented beer must be corrosion resistant, since the pH of the beer after 24 hours of fermentation time is below 2.5. Stainless steel is a suitable material of construction for such units. Continuous sterilization is conducted at 300° F. for 5 minutes at pH 6.5, the natural pH of the medium. Batch sterilization is conducted at 250° for 30 minutes at pH 5.0 or lower to prevent loss of ammonia through decomposition of the ammonium sulfate in the medium.

Incubation temperature for the fermentation is from 93° to 95° F. and inoculum amounts to 5 percent of the total fermentation substrate. A yield of 60 grams of itaconic acid per 100 grams of anhydrous glucose is obtained consistently.

The oxygen absorption rate that can be used for this fermentation is considerably lower than that used for most submerged culture fermentations. An oxygen absorption rate of approximately 0.1 millimole of oxygen per liter of liquor per minute is recommended. Rate of fermentation, or yield of itaconic acid, is not increased significantly with oxygen absorption rates above 0.1 millimole of oxygen absorbed per liter per minute. Table 3 shows the effect of rate of oxygen absorption on the fermentation. Foaming is reduced significantly by conducting the fermentation under a pressure of 12 to 15 lb./sq. in. gauge. A decrease in foam formation is accompanied by a corresponding reduction in consumption of antifoam agent. Excessive addition of antifoam agent, 0.75 percent octadecanol in ethanol, has an inhibitory effect. No further improvement in operations occurs when pressure is increased to 30 lb./sq. in. gauge.

TABLE 3.--Effect of oxygen absorption rate of itaconic acid production with organism₁
Aspergillus terreus NRRL-1960¹

OAR ²	Original : glucose	Final : glucose	Yield ³	Average production ⁴ rate
	Percent	Percent		
0.1	6.12	0.06	55.1	0.79
.15	6.40	.05	56.4	.90
.20	6.00	.04	50.4	.85
.30	6.65	⁵ 3.07	--	.62

¹ Fermentations conducted at 93° F., 12 to 15 lb./sq. in. gauge and 1 percent inoculum.

² Oxygen absorption rate, millimoles oxygen absorbed per liter per minute.

³ Grams itaconic acid produced per 100 grams of anhydrous glucose supplied.

⁴ Expressed as ml. 0.1N NaOH per hour for a 10-ml. sample.

⁵ Run discontinued; could not control foam.

Contamination is not a serious problem, since the pH of the medium after 24 hours drops to 2.5 from an initial pH of 4.0 to 5.0. This fermentation probably could be adapted to a continuous procedure. Satisfactory runs have been made in which a semicontinuous system was employed. A batch of 225 gal. was allowed to ferment completely, after which half of the beer was withdrawn and replaced with an equal volume of sterile nutrients. After the latter mixture had been fermented, the cycle was repeated and results showed that satisfactory rates and yields were obtained throughout the test.

Recovery of itaconic acid by crystallization from the filtered beer is an acceptable recovery method. Solvent extraction with butyl and isoamyl alcohols was investigated briefly, but because excessive polymerization and esterification occurred, studies on this method were discontinued. The beer filters readily in an ordinary plate and frame filter press without the use of filter aids. The filtrate is concentrated under vacuum to yield a concentrate containing more than 40 percent itaconic acid; use of a forced circulation evaporator is recommended to prevent accumulation of crystals on the heating surfaces.

Crystallization of the hot concentrate can be conducted in conventional crystallizers. Separation of itaconic acid crystals from the mother liquor can be accomplished in a perforated-basket centrifuge. The first mother liquor or centrifugate is concentrated again, after which crystallization and centrifugation are repeated. Second-crop crystals are mixed with filtered beer from a subsequent fermentation and recovery continues as described previously. This recovery procedure yields a tan product of at least 96 percent purity, and constitutes a recovery of more than 86 percent of the acid in the beer. Additional recovery of itaconic acid by crystallization from the second mother liquor is not practical but undoubtedly additional acid could be recovered by other methods.

It is necessary to treat the tan crystals with carbon to get a white crystalline product. The tan crystals are dissolved in sufficient hot water to make a 25-percent solution. Decolorizing carbon amounting to 2 percent by weight of the acid is added, and the mixture is agitated for 30 minutes. Filter aid is added in an amount equal to the weight of the carbon and the slurry is filtered in a steam-jacketed filter. Filtrate, combined with the water used for washing the cake, is run through a crystallizer; the crystals, after removal from the mother liquor by centrifugation, are dried under vacuum.

ECONOMIC ASPECTS

The ultimate choice of techniques employed in any process whether it be fermentation process or not depends not only on their technical feasibility but also upon their economic feasibility. In conjunction with our studies on fermentations under the utilization research program, preliminary estimates are made to determine an approximate cost for a process. Costs are calculated for the fermentation stage alone, as well as for the overall process. If the estimated production cost appears to be unrealistic, additional investigations are conducted to improve the economics of the operation. A breakdown of the costs for the various stages should reveal which costs are inordinately high and where reductions might best be achieved.

Although a cost estimate may indicate that the process as finally developed is the most economical one, changes may be made when the process is adopted commercially. Because there is a frequent similarity in processes conducted in the fermentation industry, a company may alter a process to permit use of existing facilities and, in particular, idle equipment. In such cases it is more advantageous economically to use such facilities rather than to use a scheme that would require the purchase of additional equipment.

During the economic analysis of a process, the choice of raw materials is examined carefully as a means of reducing costs. Carbohydrates and nitrogenous or proteinaceous materials are basic ingredients in most fermentation substrates. Farm crops generally serve as an excellent source for either one or both of these ingredients. Selection of a raw material will depend upon its availability, cost, and its effect on processing conditions and yield of product.

Cereal grains, oilseeds, or the constituents of both provide the major farm commodities now utilized by the fermentation industry. The extent to which these commodities are consumed in fermentative processes, other than for alcohol production, is difficult to predict. It has been estimated, however, that more than 40 million bushels of grain or equivalent have been utilized by industry through processes developed at the Northern Laboratory. In addition, the individual products made by these processes have achieved considerable prominence.

SUMMARY

Recent developments in the fermentation of grain constituents to industrial chemicals have provided a variety of new and useful products. The Northern Regional Research Laboratory, which has facilities particularly suited for such fermentation processes, has made numerous significant contributions to a program to increase industrial utilization of agricultural products. Proper application of unit operations, which include the use of fundamental chemical engineering principles, is essential to systematic conversion of fermentation processes from laboratory to pilot-plant to commercial scale. Problems encountered in fermentation work frequently require unique modifications in standard unit operations and development of special equipment for a process to perform satisfactorily. Cost analyses of processes are useful to determine if modifications in operating procedures should be considered and where improvements might best be made.

The types of products with desirable properties that can be synthesized in biochemical processes appear to be innumerable. We expect that our research efforts will continue in the future as they have in the past to provide practical methods for producing new and useful industrial chemicals by fermentation thereby enhancing the nation's program of agricultural utilization.

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